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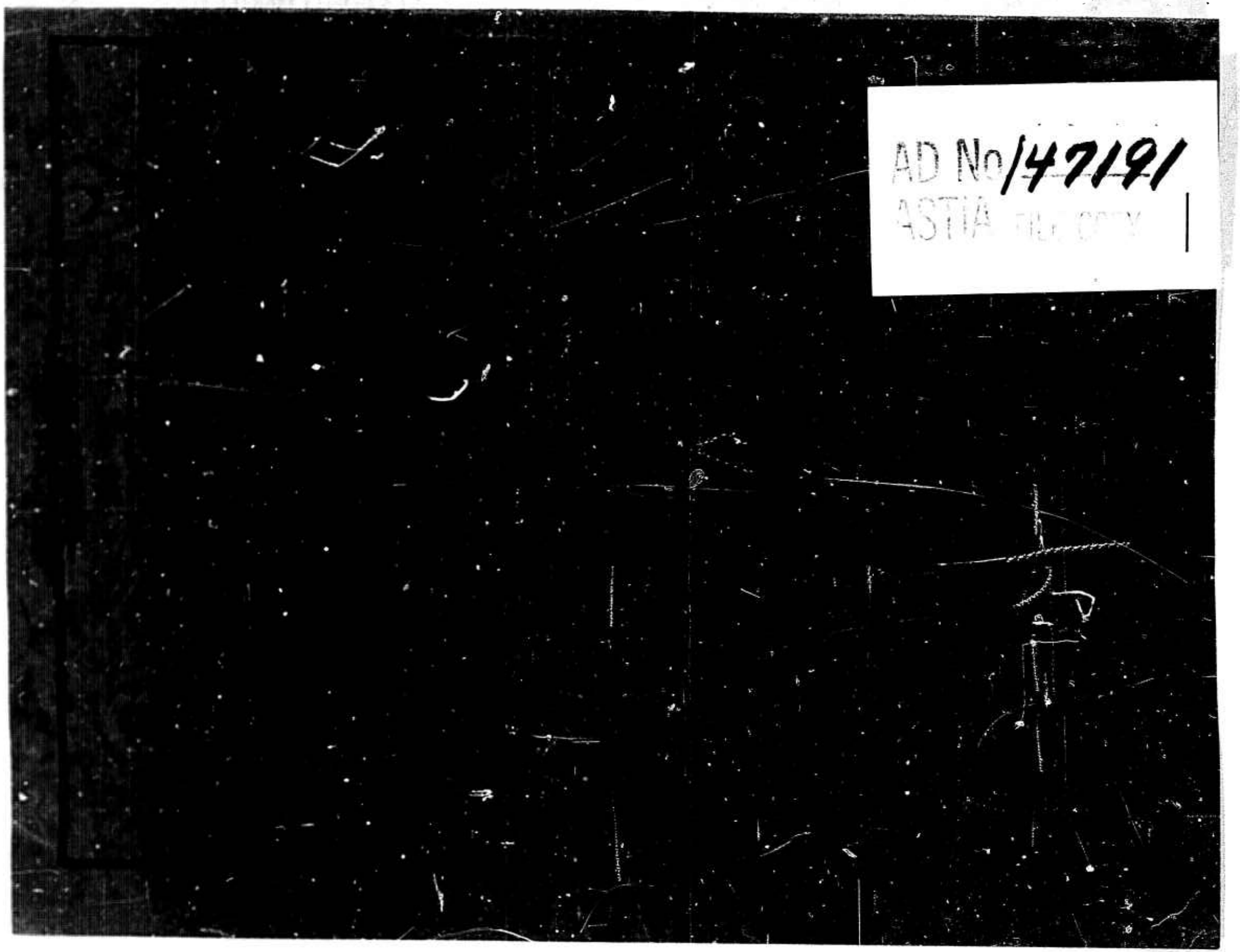

REPORT NO. R-627

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM H.E.I. SHELL M 97 (T23) WITH FUZE P.D. T71E4

FIRST REPORT

PROJECT:2/148

PREPARED BY:

EDWARD R. TELO
Physicist

REVIEWED BY:

HERSCHEL SMITH
Physicist

C. C. FAWCETT
Assoc. Director of Laboratory

APPROVED BY:

C. H. GREENALL
Lt Col, Ord Dept
Director of Laboratory

FOR:

J. B. ROSE
Colonel, U. S. Army
Commanding

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OBJECT

To take a series of high speed X-ray pictures showing the functioning of 20mm H. E. I. Shell M97 (T23) similar to the studies carried out for the 20 mm H.E.I. Shell MK-I.

SUMMARY

A series of high speed X-ray pictures have been taken which show the functioning of 20mm H.E.I. Shell M97 (T23) with Fuze P.D. T71E4 when fired through the following thickness of target plates: .012 in., 1/16 in., .083 in., 1/8 in. and 1/4 in. The pictures show the time of function, the manner of fragmentation of the shell and the formation of the hole in the plate.

At a striking velocity of approximately 2850 f/s against target plates placed normal to the line of fire the functioning of the shell is dependent on the thickness of the plate. Against .083 in. plate all shells functioned while passing through or after having passed through the plate. When fired against 1/8 in. and 1/4 in. plates the shells consistently functioned and ruptured before the bourrelets of the shells had passed through the plate. None of the shells fired against the .012 in. plate functioned. When fired against the 1/16 in. plate the shells frequently did not function until they were completely through the plate. Two shells out of 20 fired did not function at all.

The dependence of the functioning of the shell on the angle of impact and on velocity was observed on .083 in. plates. When fired at a striking velocity of approximately 2850 f/s against the plate inclined at 20° to the line of fire all shells functioned consistently and ruptured before having passed half way through the plate. Against a plate placed normal to the line of fire the shells frequently passed completely through the plate before functioning. When fired at 1600 f/s against the plate placed normal to the line of fire eight shells out of 35 fired did not function at all.

The shells swell to almost twice normal diameter before rupture is visible.

The explosion imparts a radial velocity of approximately 2800 f/s to the shell fragments.

AUTHORIZATION

OO 471.1/25916

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I. INTRODUCTION

This Arsenal has taken high speed X-ray pictures which show the functioning of 20 mm H.E.I. Shell MK-I, with Fuze No. 253 MK-II, when fired through a mild steel target (1/16 in. and 1/8 in. thick) placed normal to the line of fire. The pictures show the manner in which the shell ruptures and the formation of the hole in the target plate.[1] A request was received from the Office Chief of Ordnance to conduct similar studies for the 20 mm H.E.I. Shell M97 (T23).[2]

II. METHODS

A. Weapon

A 20 mm gun tube AN-M2 was used for the firing. An adapter sleeve was screwed on the breech end of the tube. This sleeve was threaded for the "A.E.S." screw-on firing action permitting convenient single round firing.

B. Ammunition

20 mm H.E.I. Shell M97 (T23) with Fuze P.D. T71E4 were used for these tests. A stationary radiograph of this shell is shown on Figure 1.

C. Targets

Mild steel plates (WD 1010 hot rolled annealed and pickled, or cold rolled, dead soft temper) were used as targets. The following target plates were used:

(1) .012 in. x 12 in. x 16 in. placed normal to the line of fire.
(2) 1/16 in. (.063 in.) x 12 in. x 16 in. placed normal to the line of fire.
(3) .083 in. x 12 in. x 16 in. placed normal to the line of fire.
(4) .083 in. x 12 in. x 36 in. inclined at 20° to the line of fire (70° between the trajectory and the normal to the plate).
(5) 1/8 in. (.125 in.) x 12 in. x 16 in. placed normal to the line of fire.
(6) 1/4 in. (.250 in.) x 12 in. x 16 in. placed normal to the line of fire.

The shells were fired at a striking velocity of approximately 2650 f/s through each of the above targets and also at a reduced velocity (1600 f/s) through the .063 in. target placed normal to the line of fire. A new target plate was used for each shot. The target was located 25 ft. from the muzzle of the gun.

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[1] Frankford Arsenal Ordnance Laboratory Report No. R-[illegible], "High Speed X-ray Pictures of 20 mm H.E.I. Shell MK-I" by E. H. Thile

[2] [illegible] 471.1/2591

D High Speed X-Ray Pictures

The high speed X-ray equipment (3) was used in taking the pictures. A picture showing the arrangement of the X-ray tubes and film with respect to the target and fragment protection is shown on Figure I of Frankford Arsenal Ordnance Laboratory Report No. R-480.(4)

A number of shells were fired through each thickness of plate and high speed X-ray pictures were taken at the instant of impact and at varying times thereafter.

For the targets placed normal to the line of fire two mutually perpendicular high speed X-ray pictures were taken of the functioning of each shell. A diagram of the set-up used in taking these pictures is shown on Figure 3 of Frankford Arsenal Ordnance Laboratory Report No. R-480. (5) The line of fire was varied from 2 in. to 4 in. above the horizontal film cassette. Maximum detail of the functioning of the shell was obtained on this horizontal film. The mutually perpendicular picture was taken on the vertical film. This film was located 9 in. from the line of fire and the pictures obtained on this film are lacking in detail. However the failure of a shell to function such as round 18 on Figure 5 was revealed by this vertical picture.

In the case of the .083 in. target inclined at 20° to the line of fire only a single high speed X-ray picture was taken of the functioning of the shell. The horizontal tube and film cassette arranged as shown on Figure 3 (side view) of Frankford Arsenal Ordnance Laboratory Report No. R-480 (6) were used.

All high speed X-ray pictures were taken at 360 kilo-volt peak and using Patterson #245 industrial combination intensifying screens with Eastman Blue Brand Ultra Speed X-Ray Film.

III. RESULTS AND DISCUSSION

Representative prints of the X-ray pictures are shown on the figures that follow. These were selected from a large number of pictures not herein reproduced. The descriptive material accompanying the pictures is based on an examination of the original negatives and some of the details have been lost in the reproduction process.

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(3) Frankford Arsenal Ordnance Laboratory Report No. R-169, "High Speed X-Ray Equipment" by L. A. Thilo and C. M. Hudson

(4) Ref. 1, loc. cit.

(5) Ref. 1, loc. cit.

(6) Ibid.

The pictures shown on Figures 2, 5 and 19 are direct prints from the X-ray negatives. The pictures shown on Figures 3, 4, and 6 to 18 inclusive have been copied from direct prints made from the X-ray negatives. The copied pictures have been reduced to approximately 1/3 size.

Figure 18 is included for comparing the manner in which the 20 mm H.E.I. Shell MK-I functions.

Two high speed X-ray pictures showing the fragmentation of 20mm H.E. Shell MK-III (Navy) (7) are shown on Figure 19.

Figure 5 shows two mutually perpendicular high speed X-ray pictures of one shell exploding with a time interval of approximately 44 microseconds between pictures. The average radial velocity imparted to the fragments by the force of the explosion was approximately 2800 f/s. This value agrees well with the values reported by Major Clark of Aberdeen. (8)

The X-ray pictures correlated with observations of the target plate revealed the following facts. Except where otherwise indicated the shells were fired at service velocity against target plates placed normal to the line of fire.

(1) .012 in. target plate (Figure 2)

(a) The shells did not function when fired through this thickness of plate.

(b) The windshields of the shells were not crushed up as a result of the impact.

(2) 1/16 in. (.063 in.) target plate (Figure 3,4, 5)

(a) The shells frequently did not function until they were completely through the plate. Two shells out of 20 fired, did not function at all.

(b) The shells which did function while passing through the plate ruptured when more than half way through. This resulted in only small holes (2 1/8 in. maximum diameter) being formed in the plate.

(c) The 20 mm H.E.I. Shell MK-I (Fuze #250, MK-II) when fired through the same thickness of plate all functioned. Rupture of the shells consistently occurred before the shells had passed more than half way through the plate. A hole approximately 4 in. in diameter was formed in the plate.(9)

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(7) Frankford Arsenal Ordnance Laboratory Report MR-70, "High Speed X-Ray Pictures of the Functioning of 20 mm H.E. Shell MK-III (Navy) when Fired Through 1/8 in. Mild Steel Turret Plate Normal to the Line of Fire", by E. L. Thilo

(8) Aberdeen Proving Ground Ballistic Research Laboratory Report No. 549, "Fragmentation of 20 mm H.E.I. MK-I During Its Functioning" by Major D. C. Clark

(9) Frankford Arsenal Ordnance Laboratory Report No. MR-70, loc. cit.

(3) .083 in. target plate (Figure 6, 7)

(a) All shells functioned when fired through this thickness of plate.

(b) The time at which the shells functioned varied. Eight shells out of 32 fired passed completely through the plate before functioning.

(c) Shells which functioned and ruptured before passing half way through the plate produced large holes (6-7 ins. in diameter). The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back and form the large hole.

(4) .083 in. target plate, shell fired at reduced velocity (1600 f/s) (Figure 8,9).

(a) Thirty-five shells were fired at reduced velocity through this thickness of plate. Two shells functioned after passing through the plate. Eight shells did not function at all.

(b) The other 25 shells functioned. Rupture of these shells consistently occurred before the shells had passed more than half way through the plate. These shells produced a large hole (6-7 in. diameter) in the plate.

(5) .083 in. target plate inclined at 20° to the line of fire. (Figure 10, 11)

(a) The shells all functioned consistently and ruptured before having passed half way through the plate.

(b) The explosion of the shells produced a hole approximately 2 3/4 in. in diameter in the plate. The momentum imparted to the petals on the back of the plate from the impact of the mushroomed shell base caused them to curl back and form a much larger hole (4 1/2 ins. in diameter)

(6) 1/8 in. (.125 in.) target plate. (Figure 12, 13, 14)

(a) The shells all function before passing through the plate.

(b) The shells start to swell approximately 74 microseconds after impact. Rupture of the shells takes place before the bourrelets of the shells have passed through the plate (approximately 45 microseconds after impact).

(c) The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back and form a large hole (6 - 7 in. in diameter).

(d) The 20 mm H.E.I. Shell MK-I (Fuze #253, MK-II) functioned in a similar manner when fired through the same thickness of plate. (10)

(7) 1/4 in. (.250 in.) target plate. (Figure 15, 16, 17)

(a) The shells all functioned before passing through the plate.

(b) The shells start to swell approximately 20 microseconds after impact. Rupture of the shells takes place before the bourrelets of the shells have passed through the plate (approximately 40 microseconds after impact).

(c) The momentum imparted to the petals on the back of the plate from the force of the explosion caused them to curl back to form a hole approximately 5 in. in diameter.

The shells swell to almost twice normal diameter before visible rupture takes place. The noses of the shell breaks up into fragments. In the case of the H.E.I. MK-III shell the noses of the shells remained in one piece. The fragmentation of the rest of the shells is similar to that of the MK-III shells (i. e. rupture of the shell body, mushrooming out of the base of the shell).

The fragmentation of the 20 mm H. E. Shell, MK-III (Navy), is different from the H. E. I. Shell in that the nose, body and base of the shells all break up into small fragments when the shells rupture.

IV CONCLUSIONS

The high speed X-ray pictures show the manner in which the shell function, the fragmentation pattern of the shell and the formation of the hole in the plate.

At striking velocity of approximately [illegible] against target plates placed normal to the line of fire the functioning of the shell is dependent on the thickness of the plate used. Against .040 in. thick plate all shells functioned while passing through or after having passed through the plate. When fired against thicker plate the shells consistently functioned and ruptured before the bourrelets of the shells had passed through the plate.

The functioning of the shell is dependent on the angle of impact. When fired at striking velocity of approximately [illegible] against .040 in. thick plate all shells functioned while passing through or after having passed through the plate. When fired against thicker plate the shells consistently functioned and ruptured before the bourrelets of the shells had passed through the plate. At oblique angles of impact the shells glanced off the plate.

(10) Preliminary Ballistic Test Report No. [illegible], [illegible].

fire the shells frequently passed completely through the plate before functioning. The functioning of the shell is also dependent on the striking velocity. When fired at a striking velocity of approximately 1600 f/s against the plate placed normal to the line of fire eight shells out of 35 fired did not function at all.

In order to form a large hole in the plate the shell must function and rupture before it has passed more than half through the plate.

V. RECOMMENDATIONS

It is recommended that in the development of 20 mm Incendiary, H.E.I., and H. E. Shells that the functioning of these shells be studied by means of high speed X-ray pictures.

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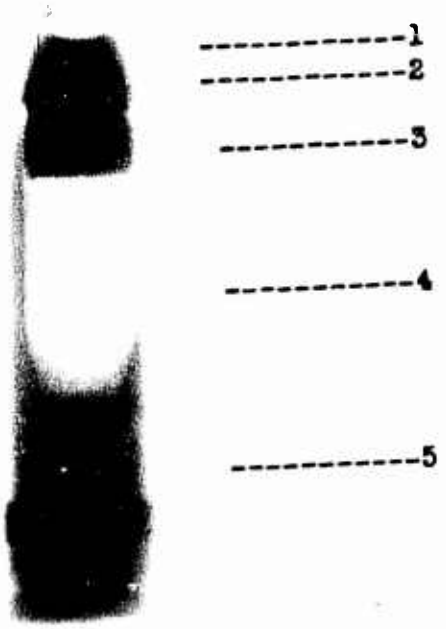
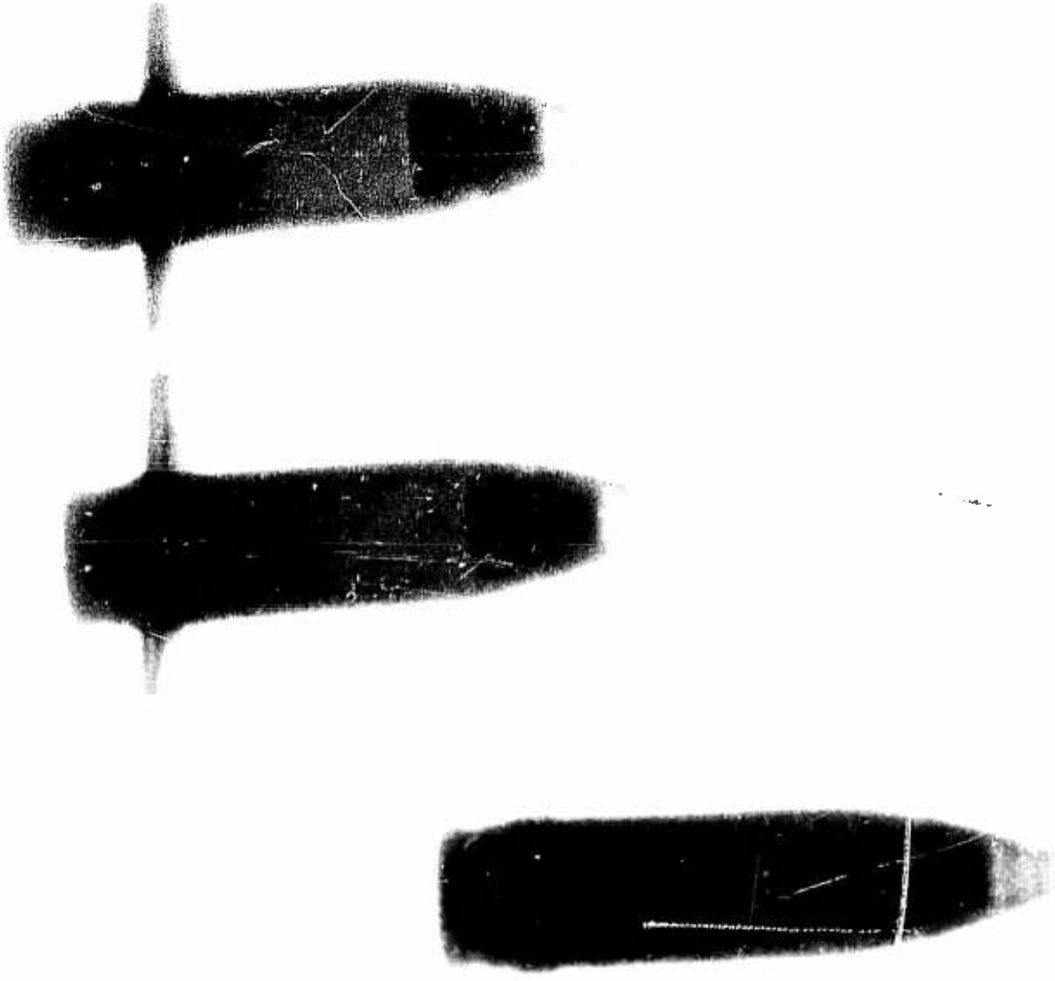


Stationary X-Ray Picture of 20 mm. H.E.I.
Shell M 97 (T 23) With Fuze P.D. T 71 E 4

1 Detonator, Approximately 5.8 grains Mercury Fulminate
2 Lower Detonator, Approximately 2.69 grains Lead Azide
3 Magazine Charge, Approximately 2,9 grains Tetryl
4 Tetryl, Approximately 83.4 grains Tetryl
5 Incendiary Composition, Approximately 34.0 grains

MKG. #1580-1 FIGURE 1 9 JUNE 1942

High Speed X-Ray Pictures of the Functioning of 20 mm. H.E.I. Shell M 97 (T 23) when fired through an .012 in. mild steel target placed normal to the line of fire. Fuze P.D. T 71 E 4.



No crush up of the windshield as a result of the impact

NEG. #15859-2 FIGURE 2 9 JUNE 1945

0
1
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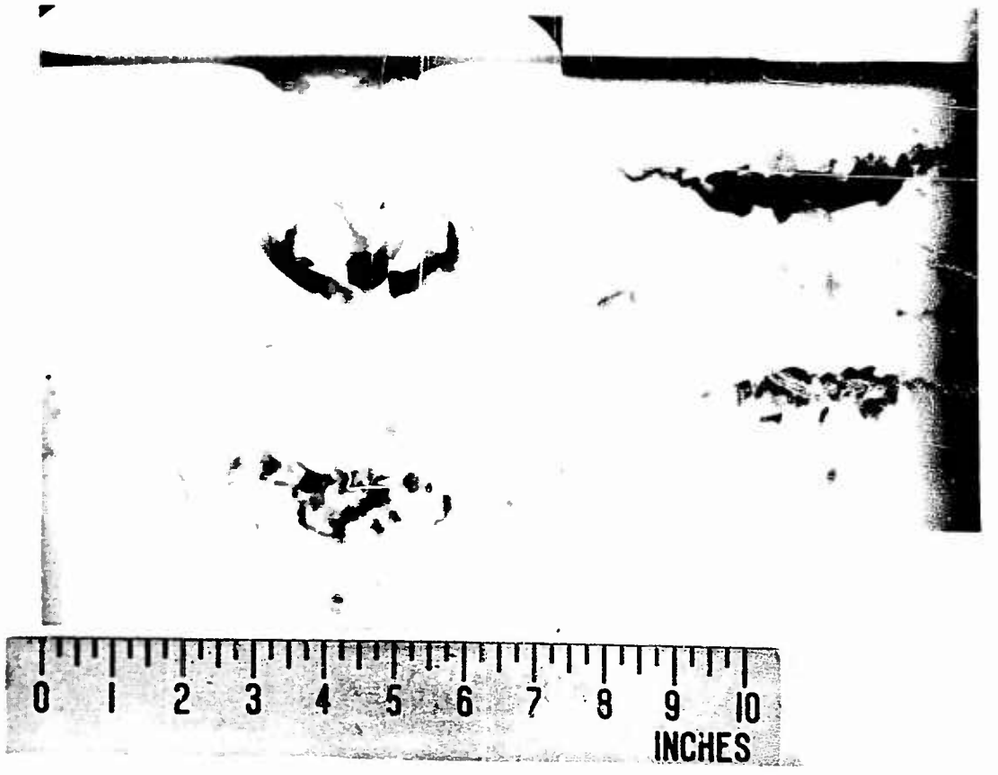
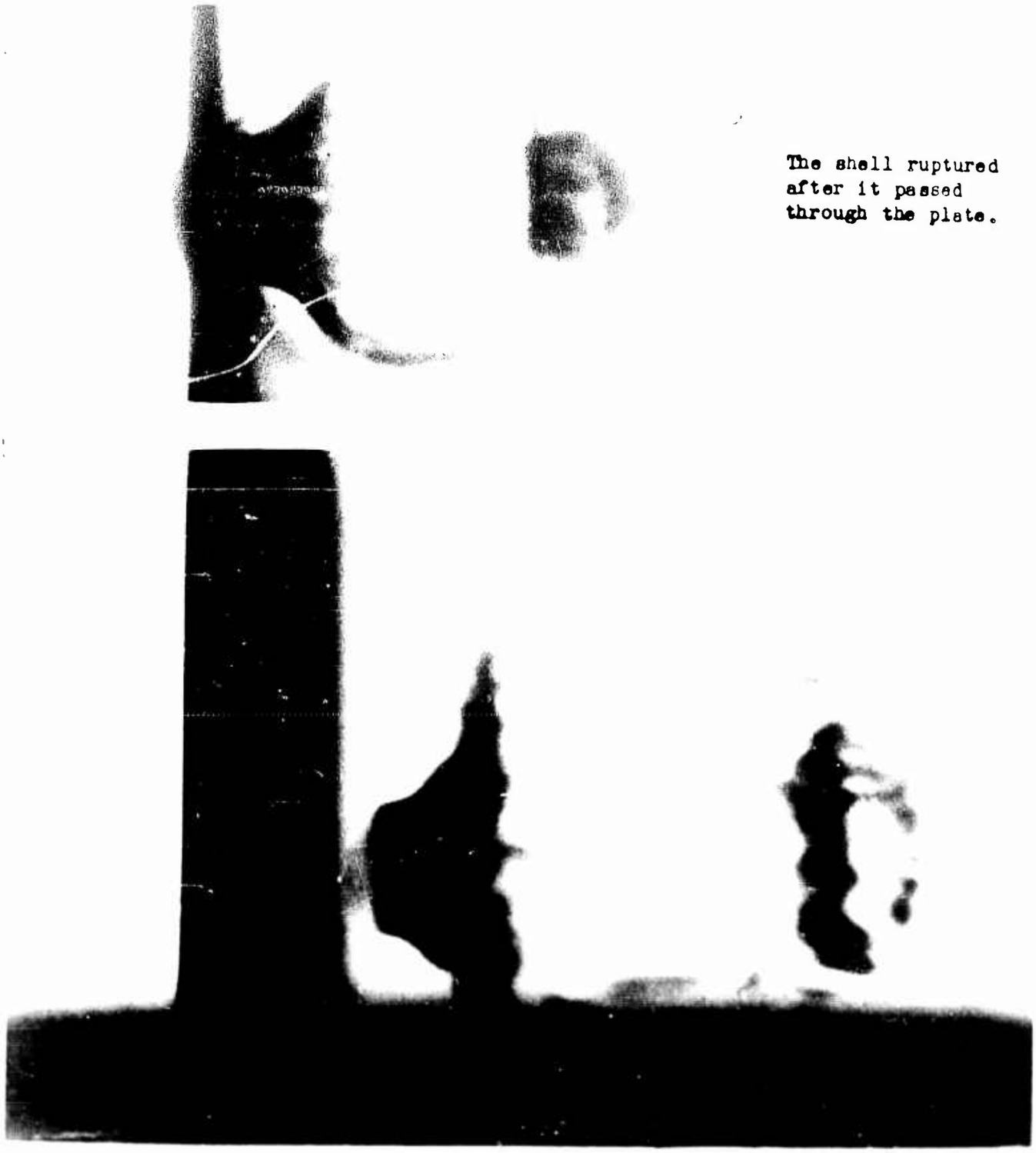
10
INCHES


0 1 2 3 4 5 6 7 8 9 10
INCHES

High Speed X-Ray Pictures of the Functioning of 20 mm. H.E.I. Shell M 97 (T 23) when Fired through a 1/16 in. mild steel target placed normal to the line of fire. Fuze P.D. T 71 E 4



The shell ruptured after it passed through the plate.

Perpendicular picture of this shell taken approximately 44 microseconds later.

NE- #10059-3 FIGURE 5 8 JUNE 1943

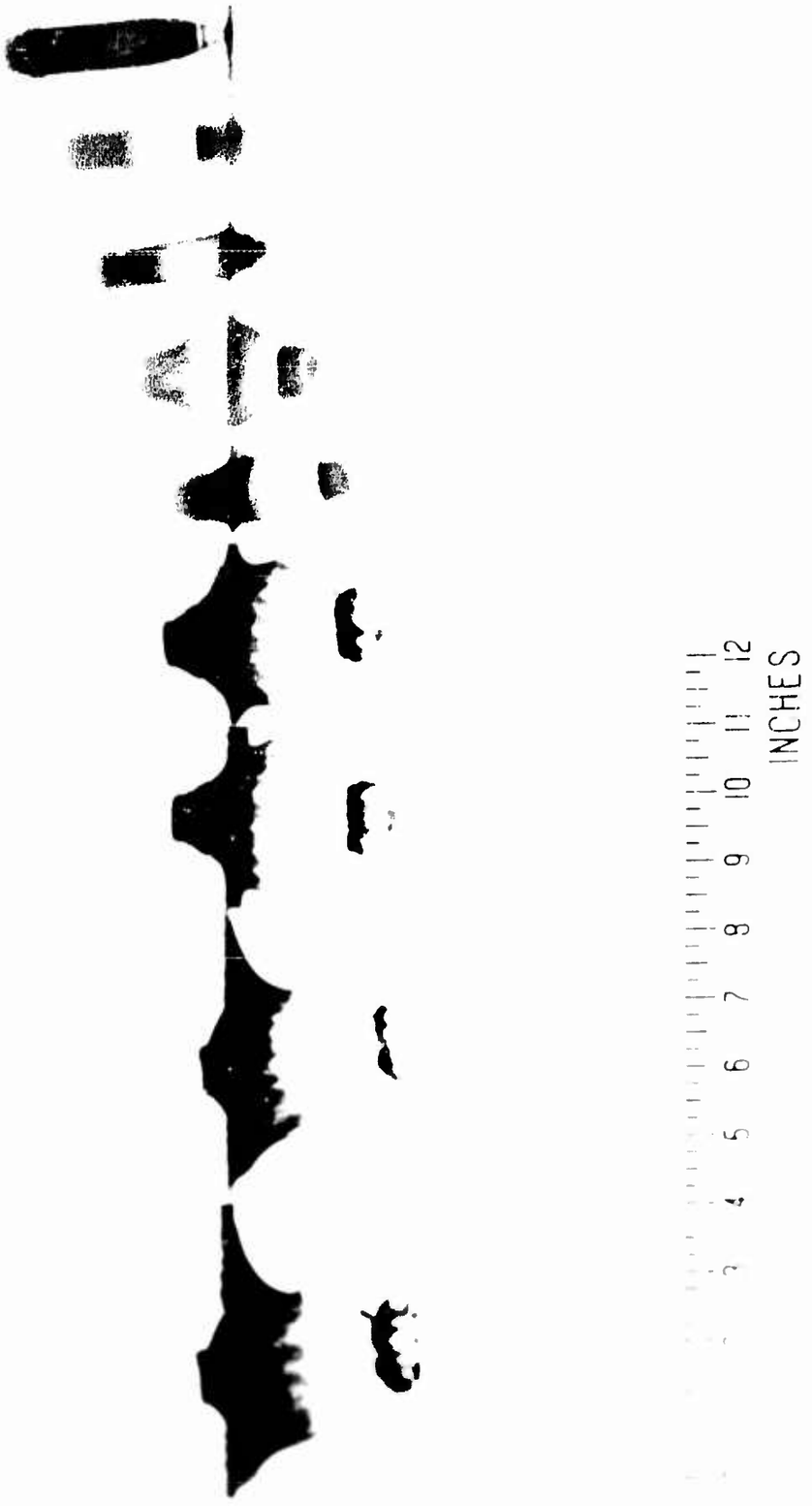
NOSE OF WINDSHIELD IN CONTACT WITH THE PLATE

THE NOSE OF THE SHELL HAS PASSED THROUGH THE PLATE. THE WINDSHIELD HAS EXPERIENCED ALMOST ZERO CRUSH UP.

THE SHELL BODY HAS SWELLED TO OVER TWICE NORMAL DIAMETER AND RUPTURED. THE METAL HAS CONTRACTED THE BOURRELET REGION OF THE SHELL FROM SWELLING AS RAPIDLY AS THE BODY OF THE SHELL. THE BASE OF THE SHELL HAS SWELLED VERY LITTLE

THE SHELL BODY HAS STARTED TO SWELL

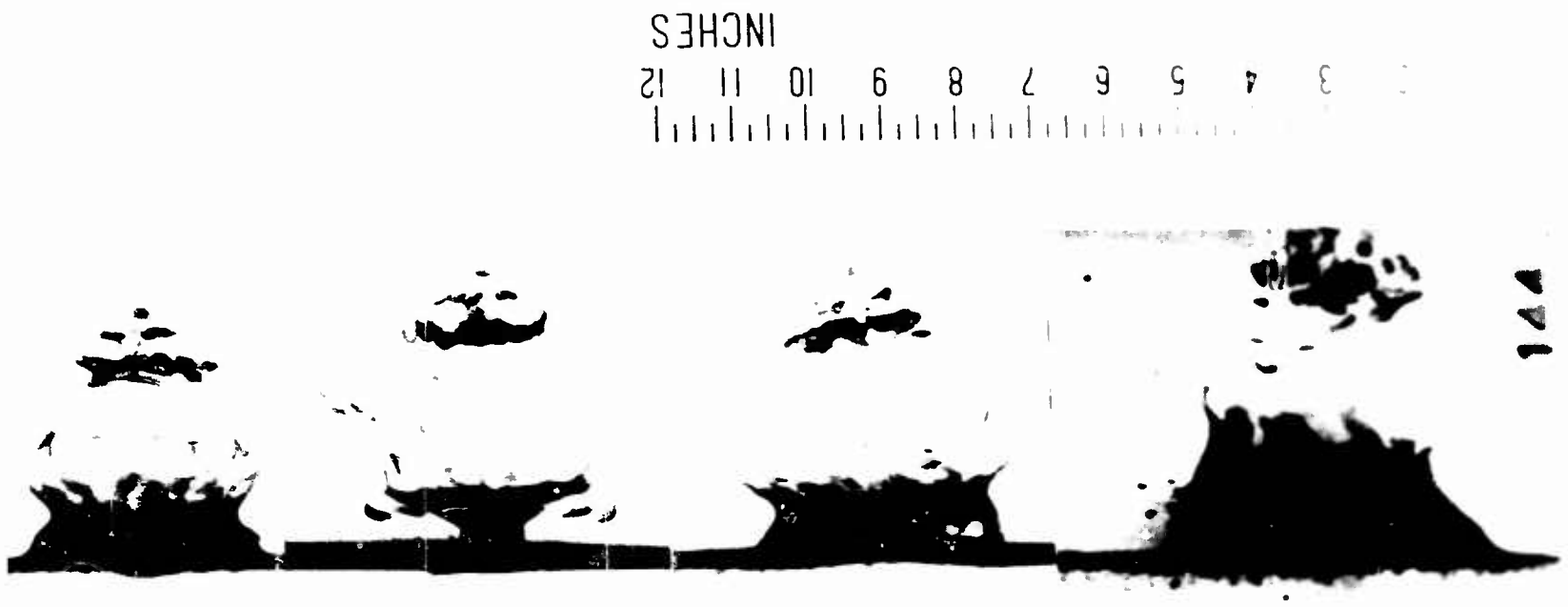
THE BASE OF THE SHELL HAS [illegible]



REG. #13604-1

FIGURE 6

9 JUNE 1965



THE FRAGMENT OF THE BACK OF THE SHELL ARE PASSING THROUGH THE HOLE.

THIS SHELL PASSED COMPLETELY THROUGH THE PLATE BEFORE IT FUNCTIONED. NO PETALS WERE FORMED IN THE PLATE.

HIGH SPEED X-RAY PICTURES OF THE [illegible] OF [illegible] SHELL WHICH [illegible] WHEN FIRED AT [illegible] VELOCITY [illegible] AND [illegible] ALL PICTURES TAKEN [illegible] NORMAL TO THE LINE OF FIRE [illegible]

THE NOSE OF THE SHELL HAS [illegible] THROUGH THE PLATE. THE WINDSHIELD HAS EXPERIENCED APPRECIABLE [illegible]

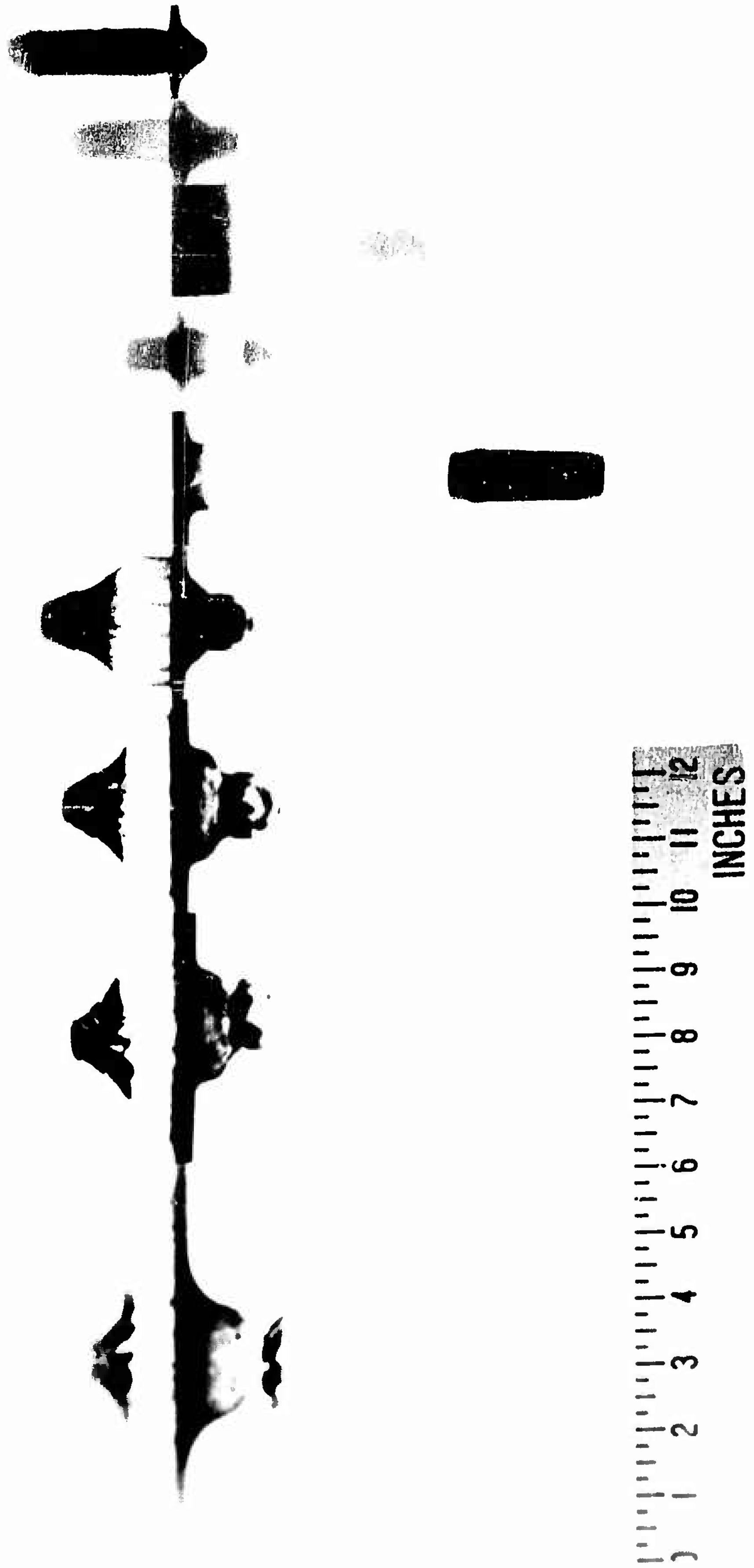
ROUND 169. THE WINDSHIELD HAS EXPERIENCED A [illegible] CRUMPLING.

MUTUALLY PERPENDICULAR PICTURE OF ROUND 169 TAKEN APPROXIMATELY [illegible] MICROSECONDS LATER. THE SHELL STILL HAS NOT FUNCTIONED. THE TIP OF THE WINDSHIELD HAS BROKEN OFF.

THE WINDSHIELD HAS EXPERIENCED VERY LITTLE [illegible] THIS SHELL DID NOT FUNCTION.

SHELL [illegible] IN [illegible] PLATE

THE SHELL BODY HAS SWELLED TO [illegible] AND [illegible] THE [illegible] REGION OF THE SHELL [illegible] OF THE SHELL. [illegible] THE BASE OF THE SHELL [illegible]



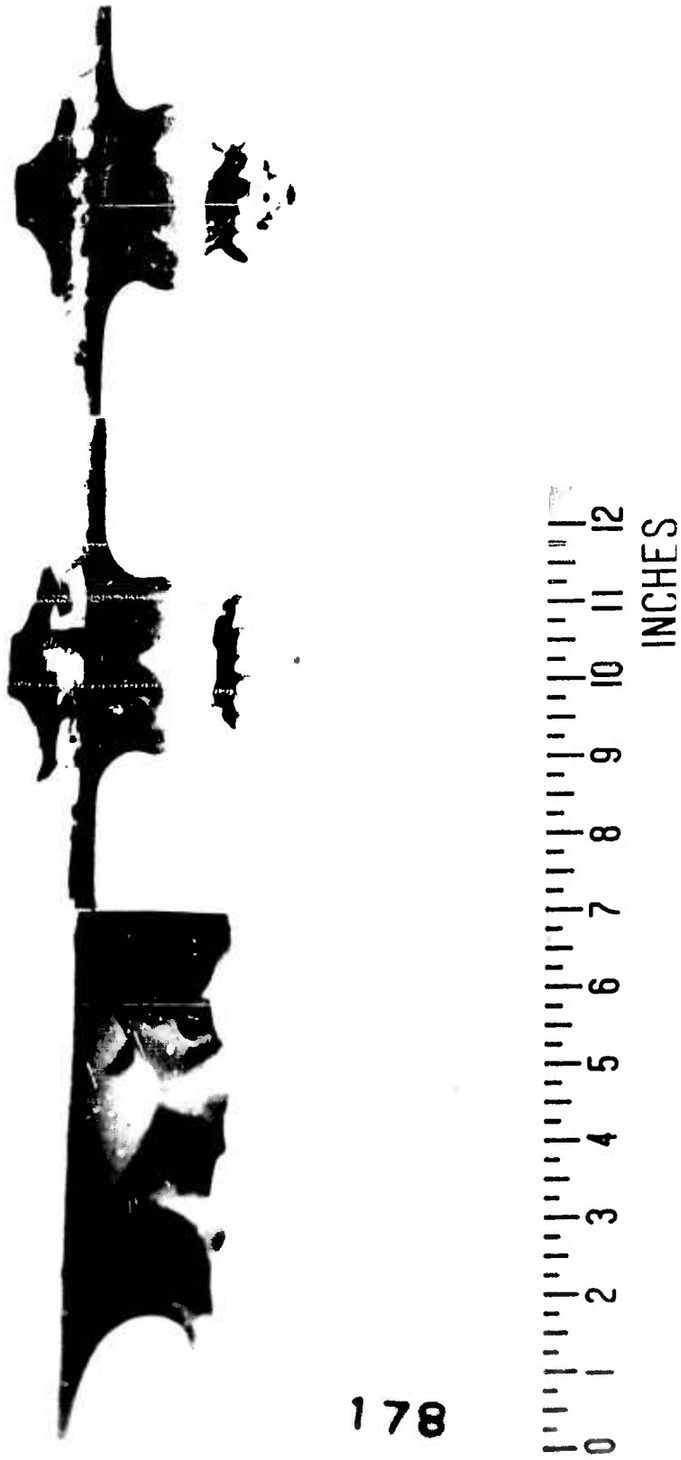
NEG. #15604-3

FIGURE 8

9 JUNE 1945

HIGH SPEED X-RAY PICTURES OF THE FRAGMENTING OF COMMERCIAL
STEEL MORTAR SHELL WHEN FIRED AT REDUCED VELOCITY (1500 F/S)
THROUGH A .030 INCH STEEL TARGET PLATE NORMAL TO THE
LINE OF FLIGHT OF THE SHELL

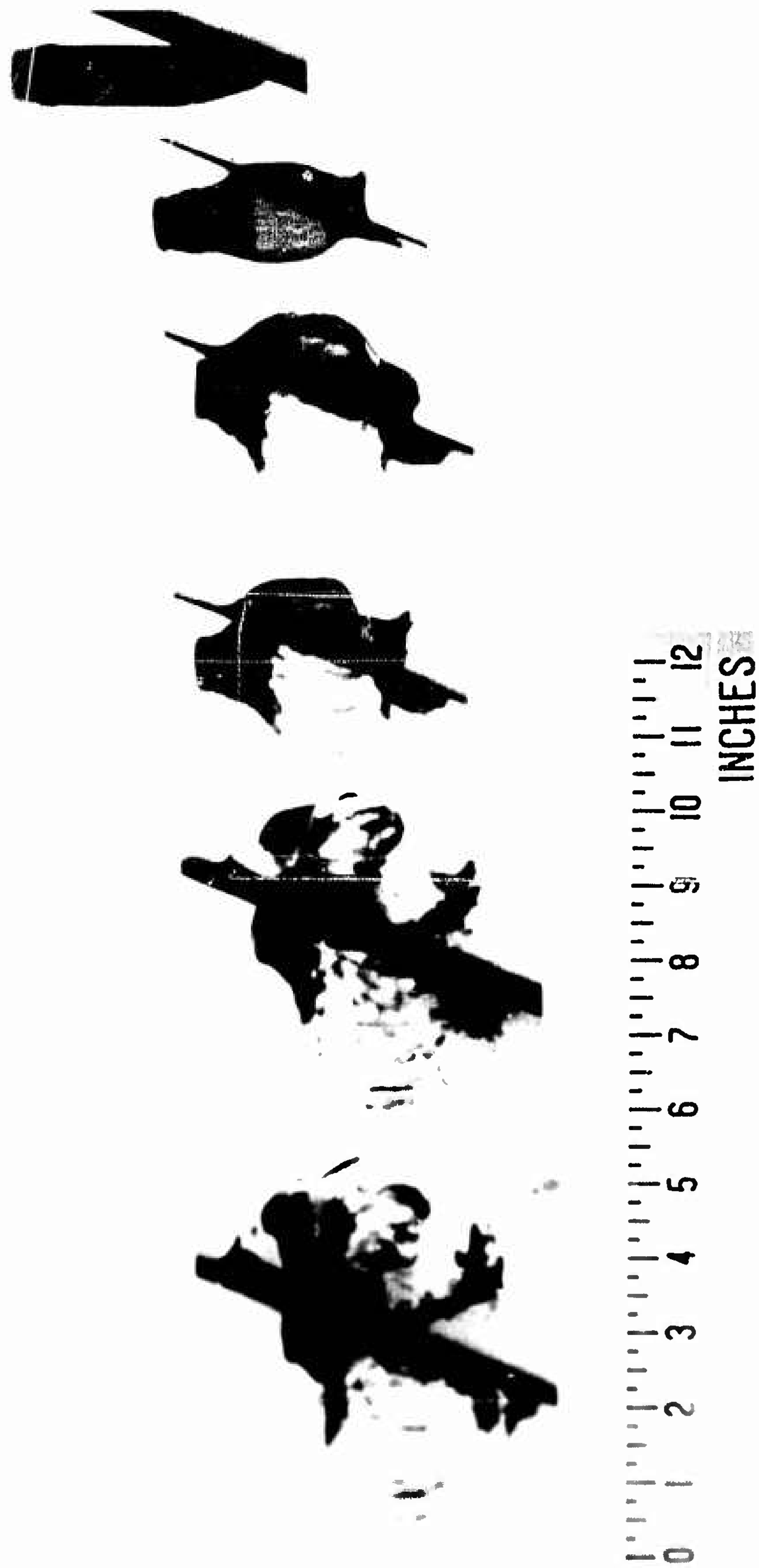
THE RATE AT WHICH SHELL IS BREAKING UP INTO FRAGMENTS
OF STEEL ARE TAKING THEIR PATH



178

NEL #15684-4 FIGURE 9 9 JUNE 1965

HIGH SPEED X-RAY PICTURES [illegible] SHELL [illegible] WHEN FIRED THROUGH A [illegible] IN. MILD STEEL PLATE PLACED AT [illegible] TO THE LINE OF FIRE. [illegible]



NOSE OF THE WINDSHIELD IN CONTACT WITH THE PLATE

THE WINDSHIELD HAS EXPERIENCED CONSIDERABLE CRUSH UP. THE SHELL BODY HAS SWELLED TO ALMOST TWICE NORMAL DIAMETER. THE BASE OF THE SHELL HAS SWELLED VERY LITTLE.

THE SHELL HAS RUPTURED. THE BASE OF THE SHELL IS STARTING TO MUSHROOM OUT. THE SHELL FRAGMENTS ON THE BACK SIDE OF THE PLATE ARE CONSTRAINED IN [illegible] RADIAL AND FORWARD MOTION BY THE PLATE PET[illegible]

NRO. #15684-3 FIGURE 10 9 JUNE 1943

NRL #15421 FIGURE 11 9 JUNE 1945

NO. 1-5400-1

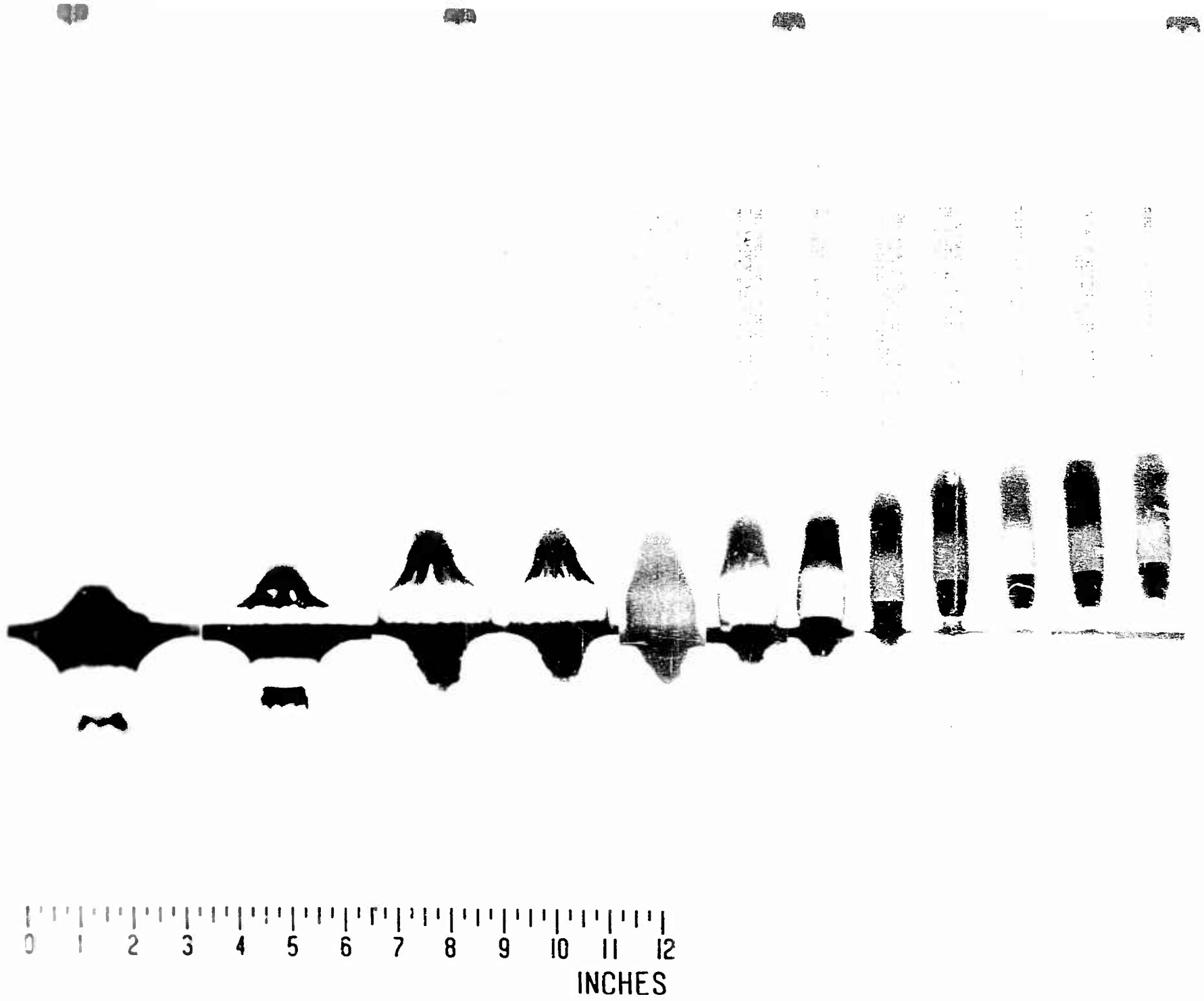
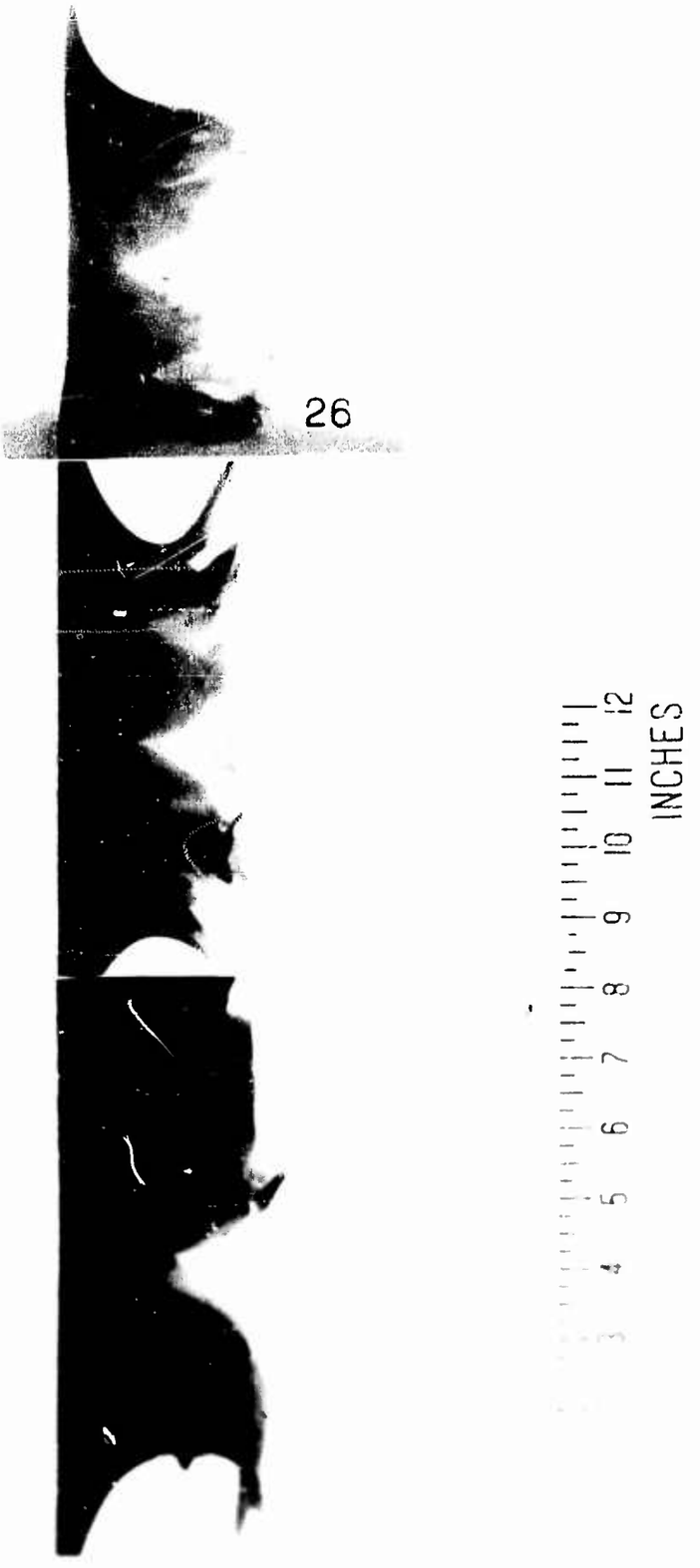


FIGURE 15

NEL. #1500-2

FIGURE 13

9 JUNE 1945



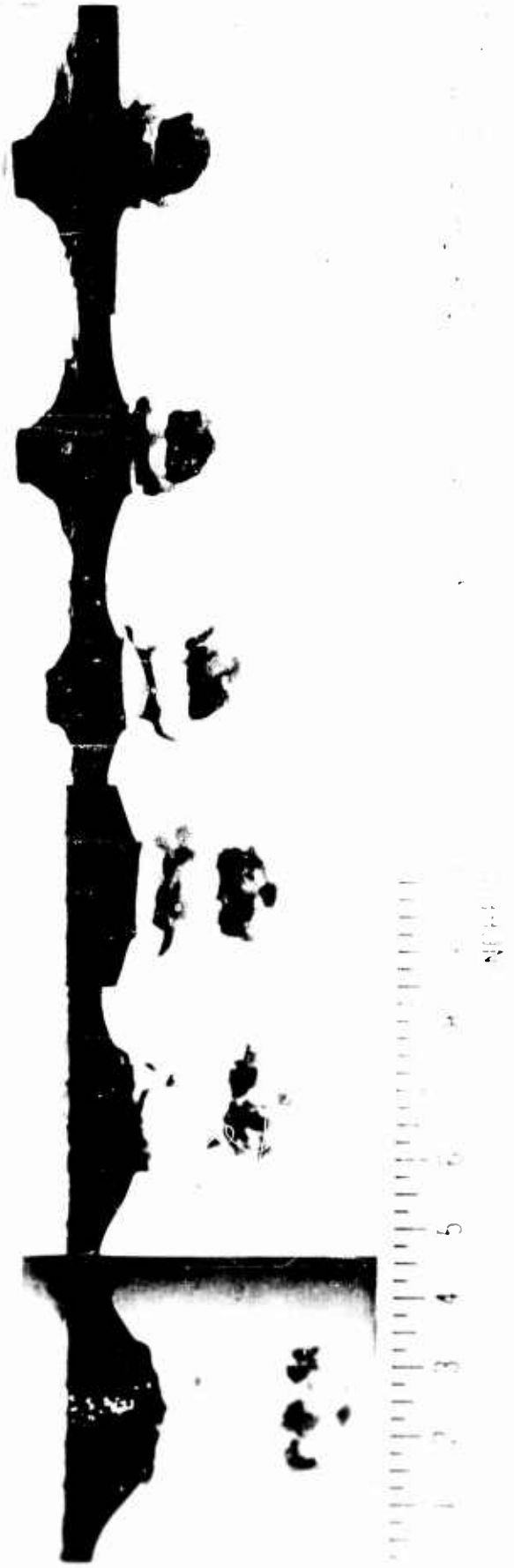
THE PETALS HAVE CURLED BACK TO PRODUCE A HOLE APPROXIMATELY 5/8 IN. IN DIAMETER.

NEG. #15CHO-3

FIGURE 14

XRD. #15155-1 FIGURE 15 9 JUNE 1948

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM. H.E.I. SHELL M 97 (T 23) WHEN FIRED THROUGH A 1/4 IN. MILD STEEL TARGET PLACED NORMAL TO THE LINE OF FIRE. FUZE PD T 71 E 4



HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM. H.E.I. SHELL M 97 (T 23) WHEN FIRED THROUGH A 1/4 IN. MILD STEEL TARGET PLACED NORMAL TO THE LINE OF FIRE. FUZE PD T 71 E 4

REF. #15155-3

PICTURE 17

9 JUNE 1943

HIGH SPEED X-RAY PICTURES OF THE FUNCTIONING OF 20 MM H E I SHELL MK I WHEN FIRED THROUGH A $\frac{1}{8}$ IN MILD STEEL PLATE PLACED NORMAL TO THE LINE OF FIRE

THE NOSE OF THE SHELL HAS PASSED THROUGH THE PLATE THERE HAS BEEN NO SHIFT OF THE DETONATING PARTS OF THE FUZE

THE SHELL HAS STARTED TO SWELL IN THE REGION OF THE BOURRELET THE BOOSTER HAS NOT YET DETONATED

THE SHELL HAS SWELLED MORE THAN THE SHELL PICTURED IN 6 THE MAXIMUM SWELLING IS STILL IN THE REGION OF THE BOURRELET THE BOOSTER HAS DETONATED THE RING OF PETALS ABOUT THE SHELL CAN BE SEEN

THE SHELL BODY HAS SWELLED TO ALMOST TWICE NORMAL DIAMETER THE PETALS HAVE CONSTRAINED THE BOURRELET REGION OF THE SHELL FROM SWELLING AS RAPIDLY AS THE BODY OF THE SHELL THE BASE OF THE SHELL HAS SWELLED VERY LITTLE

THE SHELL HAS RUPTURED THE BASE OF THE SHELL IS STARTING TO MUSHROOM OUT THE CONSTRAINING EFFECT OF THE PETALS IS EVIDENT

THE BASE OF THE SHELL HAS MUSHROOMED OUT EVEN FURTHER THE NOSE AND SOME OF THE SHELL FRAGMENTS HAVE PASSED OUT OF THE CONSTRAINING INFLUENCE OF THE PETALS

THE SHELL FRAGMENTS ARE ALMOST ALL COMPLETELY THRU THE HOLE THE PETALS HAVE CURLED BACK TO PRODUCE A HOLE APPROXIMATELY 2 IN IN DIAMETER

[illegible]

FIGURE 18

High Speed X-Ray Pictures of the Functioning of 20 mm. H.E. Shell, MK-3 (Navy) When Fired Through a 1/8 in. Mild Steel Target Placed Normal to Line of Fire

NRL #1565/1.4 FIGURE 19 6 JUNE 1945